Managing Disturbances Sources on LISA Pathfinder

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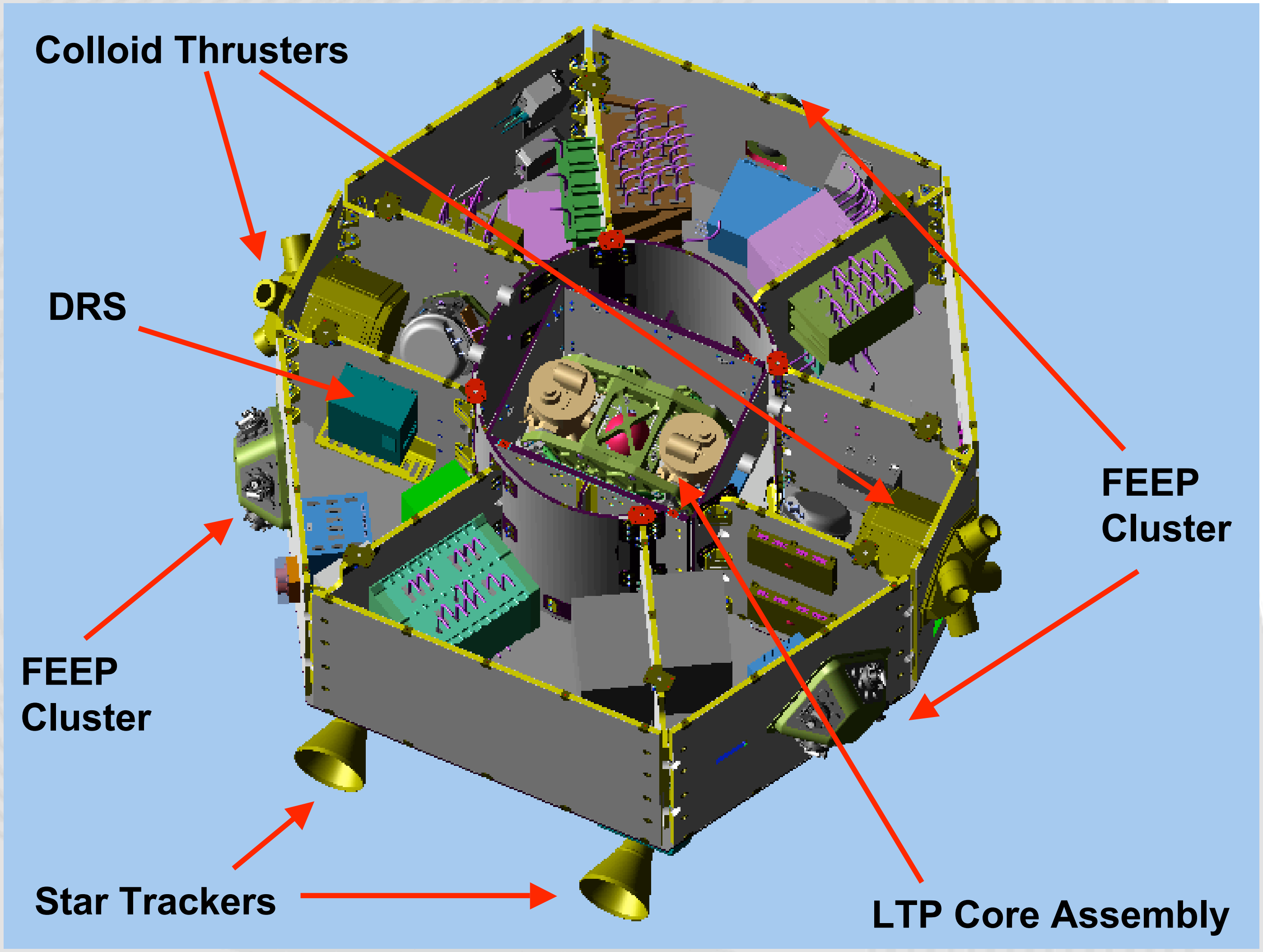
LISA Pathfinder Configuration



Primary Mission Goal - Acceleration Noise

- "*Verify that a TM can be put in pure gravitational free-fall within one order of magnitude of the requirement for LISA*"

$$S_a^{1/2}(f) \leq 3x10^{-14}\left[1+\left(\frac{f}{3mHz}\right)^2\right]\frac{m}{s^2}\frac{1}{\sqrt{Hz}}$$

$$1mHz \leq f \leq 30mHz$$

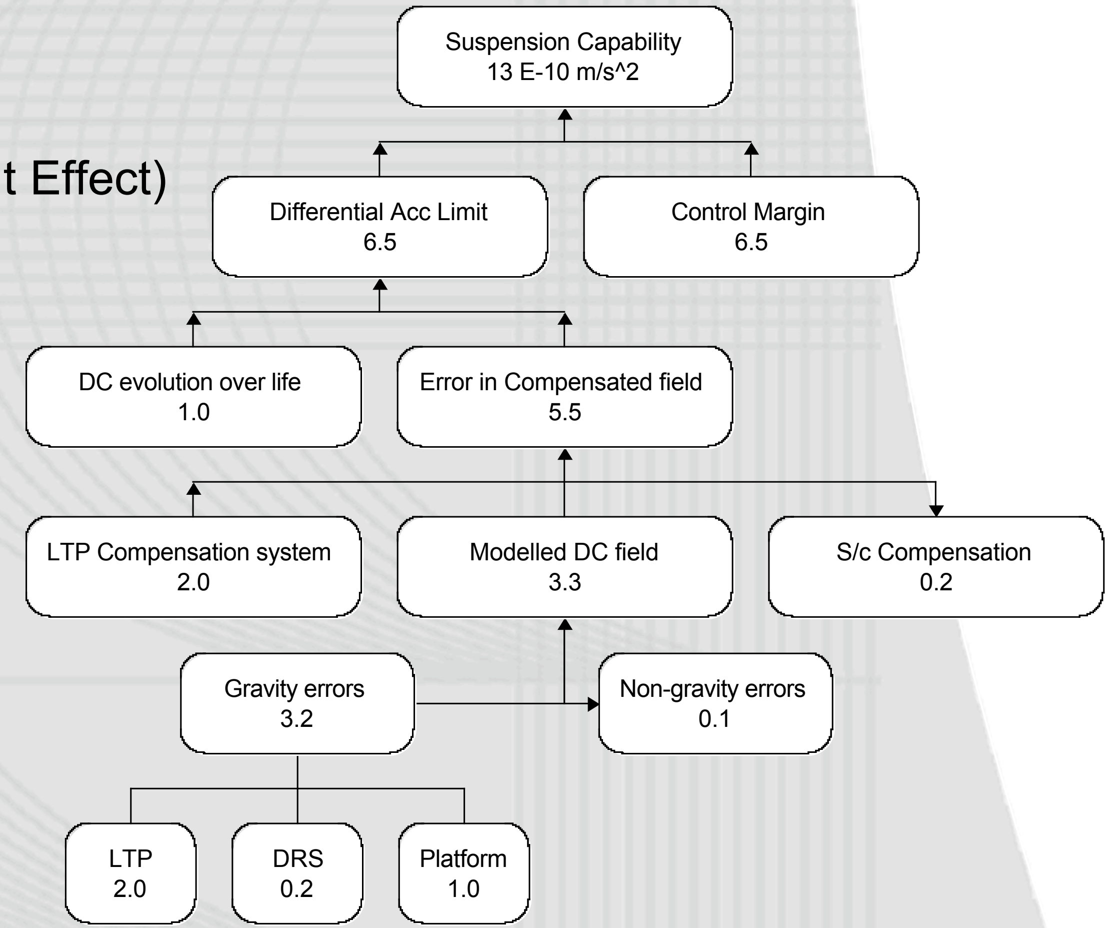
- Apportioned between known or potential disturbance sources and between contributors
  - Direct force noise caused by low frequency, time-varying forces
  - TM jitter which couples via a stiffness term
  - Optical Metrology System accuracy and alignment

Self-Gravity Disturbance Sources

- Self-gravity noise effects
  - Primarily due to thermo-elastic effects
- Actuation noise budget is 10×10^{-15} m/s^2/$\sqrt{\text{Hz}}$
  - Electrostatic suspension system compensates for differential force between TM1 and TM2
  - Necessary to limit differential force and voltage fluctuations
  - 50% of budget allocated to DC force/voltage stability
- Gravity gradient stiffness effect
- Cross-coupling of forces/torques from other axes into sensitive axis

Differential DC Force

- Number of contributors to differential DC force
  - Magnetic Field
  - Electric Field
  - Thermal Effects
  - Self-Gravity (Dominant Effect)
- Natural field exceeds suspension capability
  - Balancing mandatory



Modelling Approach

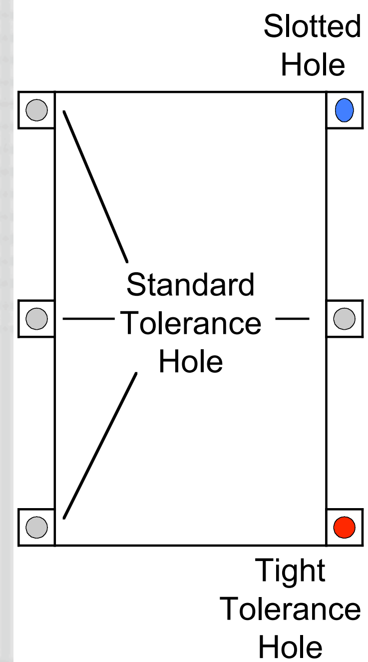
- Gravity force between source element and TMs

$$\vec{F} = \int \left(\int \vec{\nabla} \left(\frac{G\rho_{TM}\,\rho_{source}}{\sqrt{(x-X)^2 + (y-Y)^2 + (z-Z)^2}} \right) dV_{TMe} \right) dV_{source}$$

- Two source mass modelling approaches used
  - Homogenous Source Mass
    - ¬ Integrate over test mass volume and source mass volume
    - ¬ Basic shapes – Cuboid, Cylinder, Sphere
  - Point Mass Distribution
    - ¬ Integrate over test mass volume for series of point masses
- Model output at TM1 and TM2 locations
  - Force, Torques, Force Gradients (dF/dx, dF/d_), Torque Gradients (dT/dx, dT/d_)

Minimising Equipment Location Uncertainty

- CFRP Structure minimises structure distortion
  – e.g. 0g-1g transition, outgassing and moisture loss
- Panel displacement and rotation limited
  – Displacement < 0.25 mm
  – Rotation < 0.001 radians
- All panel insert locations mapped (< 0.02 mm)
- Equipment thermo-elastic expansion
  – Tight tolerance hole and slotted hole specified
  – Controls direction of expansion
  – Limits uncertainty of unit location
  – Large unit expansion causes 10^{-12} m/s^2 change



Balancing the Gravity Field

- Compensation mass minimised when close to TMs
  - Three levels of compensation masses
    - ¬ LTP Internal (mounting inside vacuum housing)
    - ¬ LTP External (mounted on vacuum housing)
    - ¬ Spacecraft Level (mounted on central cylinder)
- Spacecraft Level Compensation Masses
  - Series of fixed locations defined
  - Sets of different sized CMs available
  - Search algorithm finds sets of CMs to provide correction
  - Analysis shows that ~1×10^{-9} m/s^2 differential DC force correction can be achieved

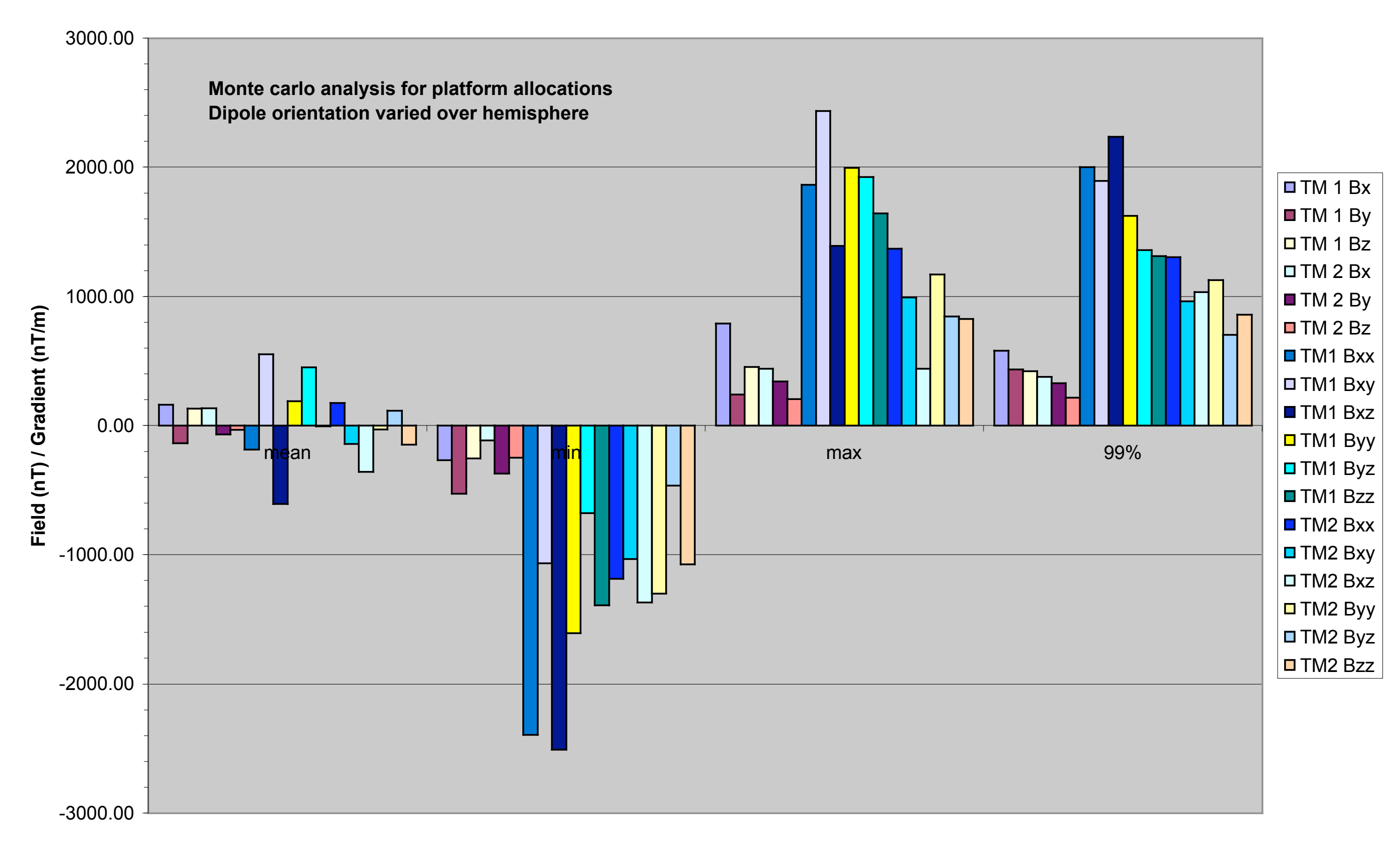
Magnetic Field Disturbance Sources

- Budget allocation of 12×10^{-15} m/s²/√Hz
- Disturbances generated by field and field gradient due to S/C sources and interaction with interplanetary field
  – Interaction of field gradient fluctuations within the MBW with permanent and induced DC magnetisation
  – Interaction of fluctuating part of induced magnetisation within the MBW with DC field gradient
  – Mixing of high frequency magnetic field fluctuations above MBW, resulting in low frequency modulation
  – Fluctuating moment in TM due to interaction with interplanetary field, interacting with DC field gradient

- S/C Requirements: Field: 5000 nT; Gradient: 2830 nT/m

Equipment Level Magnetic Field Requirements

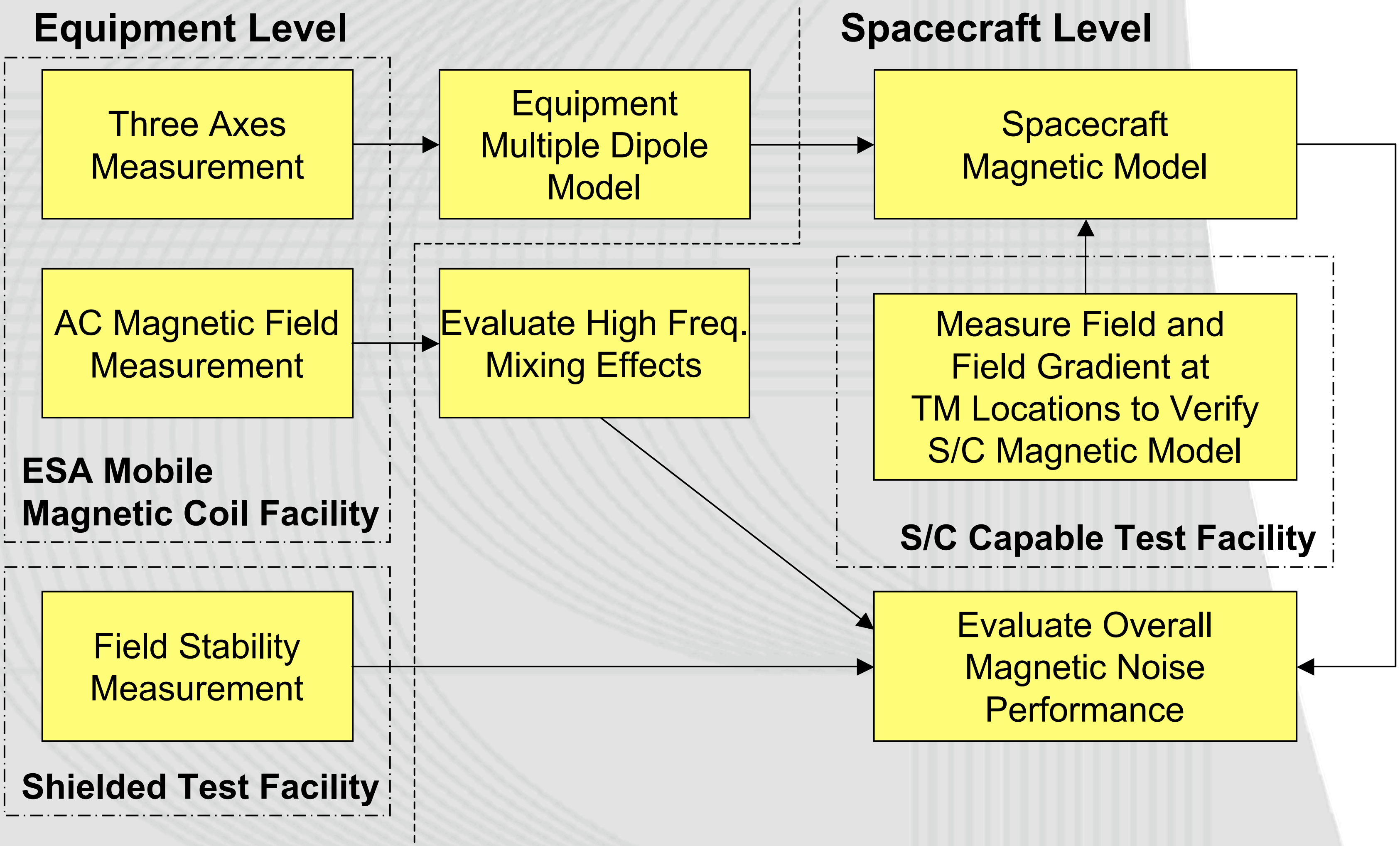
– Equipment level magnetic moment requirement set using historical data, complexity and proximity to TMs



Design Approach to Control Magnetic Disturbances

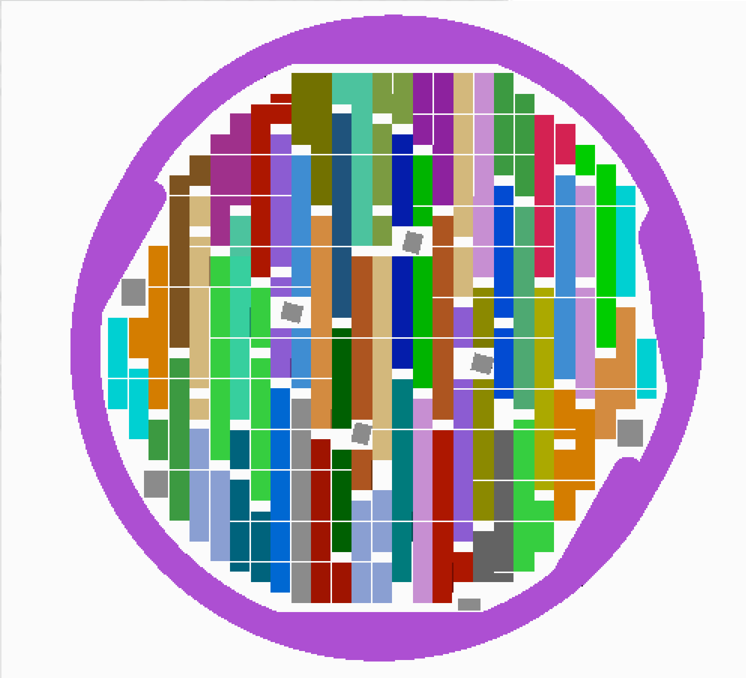
- Most effective method to control by design:
  - Avoid permanent magnets, assemblies that intentionally generate magnetic fields (relays, solenoids, etc.)
  - Appropriate selection of materials - no ferromagnetic parts
  - Minimise current levels as far as practical
  - Minimise loop area on circuit boards and harness by keeping return lines in close proximity to out-going lines
  - Avoid unintended current loops - single-point grounding, careful design of power distribution systems

Magnetic Testing



Solar Array Design

- Solar array is physically large and close to TMs
  - Not possible to use overall magnetic moment in model
  - Measurement of magnetic dipole not practical
  - Magnetic properties are entirely calculated
- Array design will be optimised to minimise magnetic field and field gradient

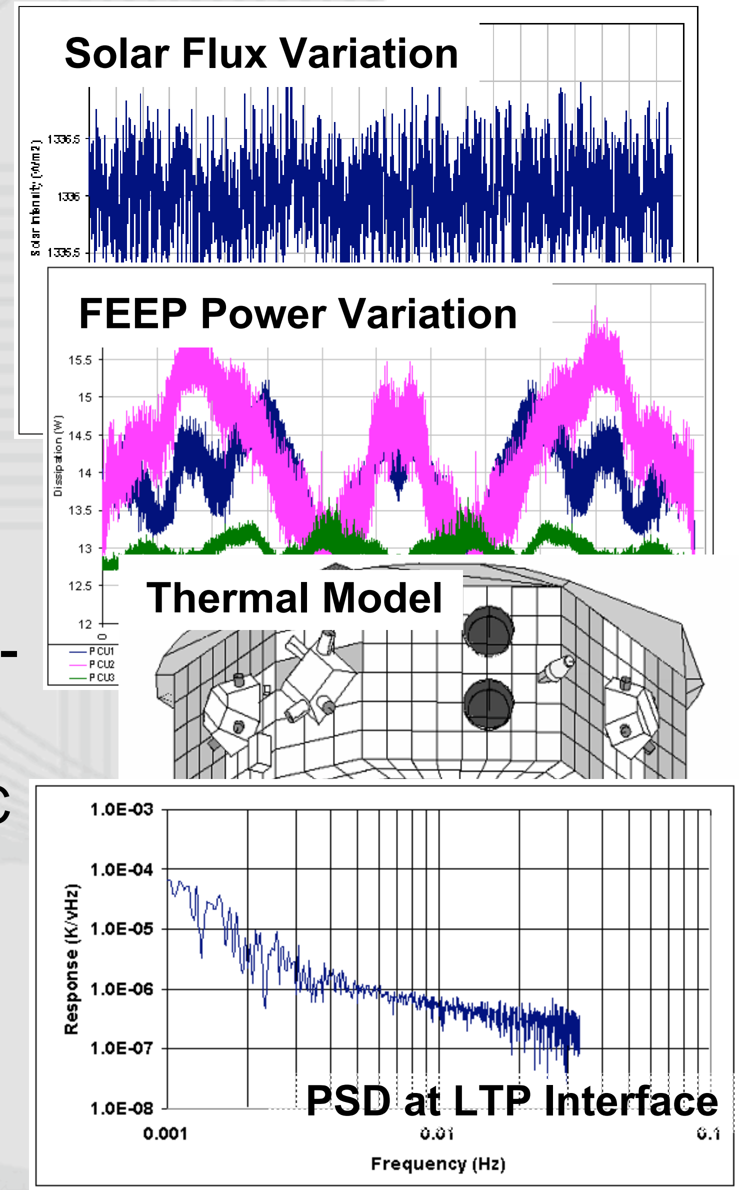


Thermal Effects

- Temperature fluctuations between S/C and LTP
  - Thermal distortion of housing and optical bench
  - Effects induced by thermal gradient across sensor housing
  - Temperature stability requirement 10^{-3} K/√Hz
- Self-gravity noise cause by thermo-elastic effects
  - Rigid-body motion of the LTP due to thermo-elastic distortions at the S/C-LTP interface
  - Causes gravity field at TMs to vary generating an acceleration noise
  - Acceleration noise requirement – 2.12×10^{-15} m/s²/√Hz
  - Translational distortion requirement – 10 nm/√Hz

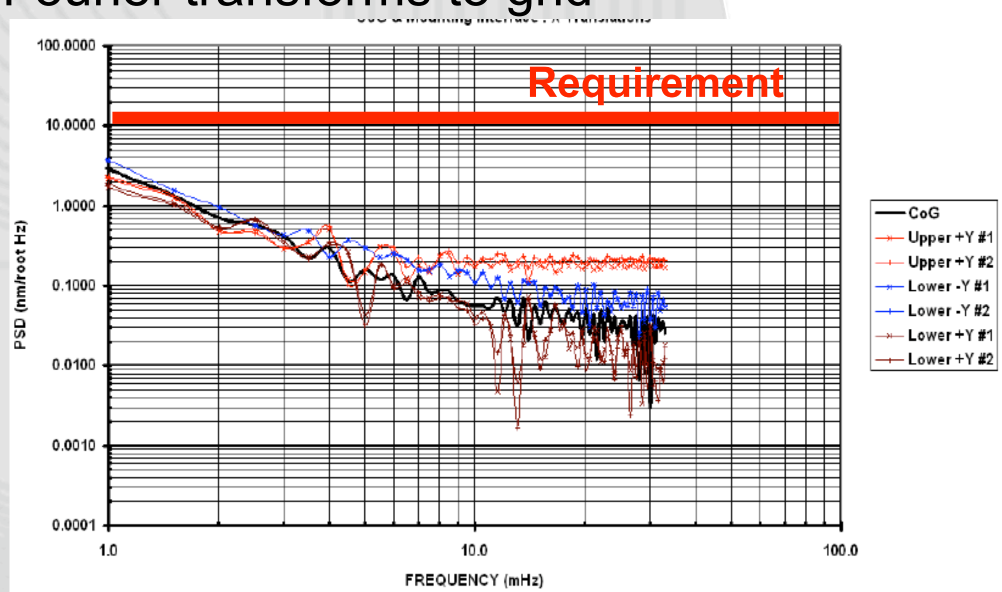
Thermal Stability

- Variation in solar flux generates noise
  - Heat fluctuations on array transmitted through structure to payload interface
  - Via DFACS which controls the attitude, causing power dissipation variations in micro-propulsion elements
- S/C thermal capacity acts as a low-pass filter
  - High frequency sources damped by S/C resistance to temperature change



Thermo-Elastic Distortion Analysis

- Input - Thermal stability analysis time histories
  - Temperature distribution mapped to FE mesh of SCM structure model
  - Thermal distortion analysis– generation of distortion time histories at LCA geometric centre and S/C LCA interface
  - PSD calculated by applying Fourier transforms to grid time histories
- A structure level thermal distortion test will be used to correlate the thermo-elastic model



Conclusions

- The impact of spacecraft level disturbances is controlled on LPF by a combination of:
  - Setting of appropriate requirements to limit or eliminate effects
  - Modelling of the disturbances
  - Testing to verify models, where feasible

Introduction to LISA Pathfinder (LPF)

- LPF a technology demonstration mission
  - LISA Test Package (LTP)
  - Drag Free Attitude Control System (DFACS)
  - Micro-Propulsion Technologies
- Launch to low Earth orbit in late-2009
- Transfer to L1 using chemical propulsion stage
- L1 provides a benign operating environment